THE FLUCTUATION OF LIMINAL VISUAL STIMULI OF POINT AREA

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I. Introduction

In a series of articles published 1906-08,[1] the writer reported the results of an experimental study of the phenomena usually attributed to fluctuation of attention. These phenomena, it was claimed, belong to three sense fields: visual sensation, auditory sensation, and cutaneous sensation. The problem was raised, it will be remembered, in 1888 by Nikolai Lange,[2] who gathered together the instances of intermittence of minimal sensations and found for them a common explanation in the conception of an instable or fluctuating attention. The recurrent changes in the limen of sensation producing the intermittence are, he contended, due to involuntary changes in the degree of attention given to the stimulus. Previous to the series of articles mentioned above, two other explanations had also been given: (a) Involuntary changes in the adjustment of the sense organ in case of vision and audition, primarily accommodation in case of vision (Münsterberg,[3]

[1] C. E. Ferree: An Experimental Examination of the Phenomena Usually Attributed to Fluctuation of Attention, *Amer. Jour. Psychol.*, XVII., 1906, 81-120; The Intermittence of Minimal Visual Sensations, *Amer. Jour. Psychol.*, XIX., 1908, 59-129; The Streaming Phenomenon, *Amer. Jour. Psychol.*, XIX., 1908, 484-503.

[2] N. Lange: Beiträge zur Theorie der sinnlichen Aufmerksamkeit und der activen Apperception, *Philosophische Studien*, IV, 1888, 389-422.

[3] Hugo Münsterberg: Schwankungen der Aufmerksamkeit, *Beiträge zur experimentellen Psychologie*, Freiburg, 1889, 69-124.

Heinrich,[4] and Heinrich and Chwistek);[5] and (b) an overflow of excitation from the circulatory and respiratory centers in the brain (Münsterberg,[6] Lehmann,[7] Slaughter,[8] Taylor,[9] etc.).[10]

In the series of articles mentioned above it was shown on the negative side that in case of vision at least, intermittence cannot be ascribed to any of the previously mentioned causes; and on the positive side that it is a phenomenon of the adaptation and recovery of the sense organ. Intermittence was denied in case of minimal cutaneous sensation,[11] and the

[4] W. Heinrich: Die Aufmerksamkeit und die Funktion der Sinnesorgane, *Zeitsch, f. Psychol.*, XI., 1896, 59-76; and Ueber die Intensitätsänderungen schwacher Geräusche, *ibid,* XLI., abt. 2, 1907, 57-59; Zur Erklärung der Intensitätsschwankungen eben merklicher optischer und akustischer Eindrücke, *Bulletin International de l'Academie des Sciences de Cracovie,* Nov., 1898, 363-382.

[5] W. Heinrich und L. Chwistek: Ueber das periodische Verschwinden kleiner Punkte, *Zeitsch. f. Psychol.,* XLI., Abt. 2, 1907, 59-74.

[6] *Loc. cit.*

[7] Alfred Lehmann. Ueber die Beziehung zwischen Athmung und Aufmerksamkeit, *Philosophische Studien,* IX., 1894, 66-95.

[8] J. W. Slaughter: The Fluctuations of the Attention in Some of their Psychological Relations, *Amer. Jour. Psychol.,* XII., 1901, 313-334.

[9] R. W. Taylor: The Effect of Certain Stimuli upon the Attention Wave, *Amer. Jour. Psychol.,* XII., 1901, 335-345.

[10] Münsterberg ascribed to this overflow, in case of respiration, an effect on the muscular control of the eye. During inspiration there was more accurate control of fixation and accommodation and during expiration a less accurate control of these adjustments. Lehmann leaves us in some doubt as to just how he believes the effect is produced. He says (op. cit., p. 84): "Wir sahen dass die Reactionen am haufigsten sind in der Nähe des Inspirationsmaximums. Hier ist eben der Blutdruck am grössten, und von diesem Zustand muss angenommen werden, dass er für die psychologische Arbeit des Gehirns günstig sei. Wir wissen ja, dass das Blut, während der Arbeit irgend eines Organes, demselben reichlicher zufliesst. Deshalb ist es höchst wahrscheinlich, dass auch die Arbeit eines Organes erleichtert werde wenn durch irgend eine Ursache eine Vergrösserung des Blutzuflusses herbeigeführt wird." Slaughter and Taylor are inclined to believe that the overflow affects the sensory cells directly. In their experiments a plethysmographic record of the peripheral blood pressure was taken while the fluctuations of the visual stimulus were being observed. They conclude that their results show a coincidence between the maxima of the plethysmographic curve and the phase of visibility of the fluctuation record. Two kinds of maxima are found in the plethysmographic tracing, one due to inspiration and the other forming the crest of a long vaso-motor wave of unknown cause, commonly called the Traube-Hering wave.

[11] In 1907 the experiments in cutaneous sensation were repeated by Geissler (L. R. Geissler: Fluctuation of Attention to Cutaneous Stimuli, *Amer. Jour. Psychol.,* XVIII., 1907, 318-321). A mistake

phenomenon was left open for further consideration in case of auditory sensation. A part of the work done at this time still remains unpublished. Some of it covers points still in dispute. For that reason two articles will be added to the former series. The first is in answer to an article by Heinrich and Chwistek entitled: "Ueber das periodische Verschwinden kleiner Punkte,"[12] and is intended to clear up, if possible, at least so far as the writer's work is concerned, the last point in dispute between the adaptation and accommodation theories. Heinrich and Chwistek maintain that the fluctuation of minimal visual stimuli of point area is caused by periodic changes in the curvature of the crystalline lens and offer their results for stimuli of point area as evidence that the fluctuations of stimuli of all areas are caused by changes in accommodation. In one of the former studies[13] the present writer had worked with stimuli ranging from 2 mm. x 2 mm.—42 cm. x 38 cm. in area. He found that stimuli of these areas fluctuate just as readily for aphakial as for normal subjects, and that changes in accommodation, therefore, can not be considered an essential factor in the production of the phenomenon. It had never occurred to him to work with stimuli of point area. In the present study, however, stimuli

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was made by him in interpreting the writer's method of stimulating the tongue electro-cutaneously that has not yet been corrected. He says, "In repeating Ferree's experiment with electro-cutaneous stimulation of the tongue, we found some difficulty in eliminating the touch, pressure, and taste sensations set up by the electrodes. The best results were obtained by applying a 1% solution of cocaine to the fore part of the tongue, upon which two strips of tin foil (Christmas tree foil), hammered as thin as possible, were laid. The strips were connected with the interruptor of a Du Bois-Reymond induction coil." Christmas tree foil was not used in the original experiments. This material was rejected at once by the present writer as unsuitable. It is much too stiff and gives rise to pressure sensations. Narrow strips of very thin and pliable wrapping foil were used instead. When these were placed on the fore part of the tongue moistened with spittle, the observer was utterly unable to tell whether or not they were in contact with the tongue when the coil was not working. Neither did they under the action of the current give rise to taste sensations. Of the two procedures the writer would prefer the one used in the original experiments. It seems to him obviously better to make the electrodes of wrapping foil than to use the stiffer material and cocainize the tongue into insensibility to contact, more especially since Geissler's observers report that the cocaine itself sets up distracting sensations in the tongue.

[12] W. Heinrich and L. Chwistek: *Zeitschr. f. Psychol.*, XLI., 1907, 39-74.

[13] See An Experimental Examination of the Phenomena Usually Attributed to Fluctuation, 98-108.

of point area have been used. From the results of this study it will be shown that the fluctuations of these stimuli present no especial case; for (a) they occur just as readily for aphakial subjects as for subjects with normal eyes; and (b) identified by the tests used by the writer in his earlier experiments they correspond just as closely to adaptation phenomena as do the fluctuations of stimuli of larger area. In the second paper, work on the fluctuation of auditory stimuli will be reported. In this work the writer has succeeded in getting conditions under which no fluctuations occur, whether the stimulus be tone or noise. His results also enable him to explain without recourse to central factors or the tensor mechanism of the middle ear the fluctuations which do occur under experimental conditions different from those he has used. The completion of these two pieces of work rounds up, so far as the writer knows, all of the outstanding points in his case against fluctuation of attention in its original meaning.

II. The Accommodation Theory

That involuntary changes in accommodation are a factor in causing the fluctuation of minimal visual stimuli was proposed first by Münsterberg in 1889.[14] Münsterberg held that the fluctuation of these stimuli is due to two causes: unsteadiness of fixation and involuntary changes in accommodation. Although different views may be held with regard to the essential physiological and psychological factors in attention, all must agree, he says, that when a visual stimulus is attentively observed the eye is fixated and accommodated so as best to receive the impression on the retina. But this adjustment cannot be uniformly maintained for any length of time. Involuntary changes both in fixation and accommodation occur. These changes weaken and confuse the light impression received on the retina, hence an object just noticeably different from its background will alternately disappear into this background and become distinct from it.

The effect of lapses in accommodation is too obvious, he thinks, to need special explanation. The rays of light are no longer sharply focused on the retina and the image of the object blurs and becomes indistinguishable from its background. For unsteadiness of fixation, however, the case is not quite so clear. The explanation is as follows. Fick, Kirschmann, and others have shown that the sensitivity of the retina to colorless light attains its maximum at a certain

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[14] Hugo Münsterberg: Schwankungen der Aufmerksamkeit, *Beiträge zur experimentellen Psychologie, Freiburg,* 1889, pp. 69-124.

distance from the fovea. Thus when the eye loses its fixation, the image of the object fixated travels towards a more sensitive part of the retina. This will cause the image of the rings on the Masson disc, for instance, which in the traditional fluctuation experiment are made just noticeably darker than their background, to lighten and become equal in brightness to the background. This gives the phase of invisibility. When fixation is regained, however, the ring again becomes noticeable. This gives the phase of visibility. These two factors, then, the lightening of the image of the ring due to involuntary changes of fixation and the blurring of its outlines due to involuntary changes in accommodation, should, according to Münsterberg, be considered as the cause of the alternate appearance and disappearance of the rings on the Masson disc which were attributed by Lange to fluctuation of attention. Since the writer has already shown in his first article[15] that involuntary changes in accommodation cannot be considered as an essential factor in these fluctuations,[16] space will be taken here only to point out that changes in fixation should also not be considered essential factors in the sense in which Münsterberg considers them factors. In the first place they could, in any event, have an effect only in case the stimulus was darker than the background. If the stimulus were lighter than the background, the brightening of the image would make it stand out more distinctly from the background than before, instead of causing it to disappear into the background as it is observed to do in fluctuating. Moreover, the explanation can have little or no application to the fluctuation of colored stimuli. Since both of the latter classes of stimuli fluctuate just as readily as the former, the principle can be regarded as having little value for purposes of explanation. And in the second place, this factor could not in all probability even cause the fluctuation of stimuli darker than the background, for the increased sensitivity of the extra-foveal retina would not only cause the ring to brighten, but also the background immediately surrounding it. The effect of the factor would

[15] See An Experimental Examination of the Phenomena Usually Attributed to Fluctuation of Attention, pp. 84 and 94-96.

[16] In the original article stimuli ranging in area from 2 mm. x 2 mm.-38 cm. x 42 cm. were used. For the writer's observers fluctuations never occurred when a stimulus 38 cm. × 42 cm. or larger was observed at a distance of 1 meter. In the experimental portion of the present paper it will be shown that changes in accommodation are not an essential factor in the fluctuation of stimuli of smaller area than 2 mm. x 2 mm., namely stimuli of point area. Thus with the present paper the demonstration will have been finished for the whole range of areas for which fluctuation occurs.

thus be merely to raise both the gray of the stimulus and of the background in the brightness scale, not to make them equal, unless indeed one were affected more than the other by an amount that would be noticeable in sensation, which can hardly be possible since the difference between them is, to begin with, only just noticeable.[17]

Münsterberg supported his explanation by the following experimental evidence. The norm of the period of fluctuation was established for each of his subjects and the following variations of conditions were made. (1) A "prismatische Lorgnette" which moved the field of vision slightly to one side was placed before the eyes. When this was held steadily in position, the period of fluctuation was affected very little, but when it was removed and interposed every 2 seconds, causing the eye to move quickly to the side to follow the shift in the object fixated, the period was very noticeably lengthened. (2) Involuntary blinking was caused every 2 seconds by means of a sharp sound. Fluctuation was prevented. When the eyes were closed voluntarily every 2 seconds, the same results were obtained. This, Münsterberg thinks, was because of the relief of muscular strain produced by the blinking. That is, as the lids are closed, the eyes move downwards and inwards; as they are opened, upwards and outwards (Bell's phenomenon). This frequent relief from the strain of fixating and accommodating so freshens the muscles, he thinks, and improves their action that disappearance never ensues. (3) The whole apparatus bearing the Masson disc was slowly moved back and forth, up and down, and sidewise. Each movement was executed in 2 seconds. Thus, in order to fixate the moving stimulus, the eye was kept continuously moving. The accommodation was also kept continuously changing. In a companion series of experiments the head was moved slowly from side to side. In this case also, in order continuously to fixate the stimulus the eye was compelled to move.[18] Fluctuation did not occur in either series of experiments. Again Münsterburg thinks fluctuation was prevented because the muscles were kept in such a fresh condition that accurate fixation and accommodation could be maintained throughout the observations. A moment's reflection will show (1) that these assumptions cannot be wholly true. The attempt of the eye to follow the moving stimulus, whether the movement was apparent, produced by the interruption of the "prismatische Lorgnette" or actual, produced by the moving of the apparatus bearing the stimulus, must have resulted in the image falling now to this side, now to that side of the fovea. If so, the fixation maintained was far from accurate.[19]. Likewise when fixation was lost in blinking, it was doubt-

[17] If, for example, one were very much lighter or darker than the other, the greater sensitivity of the extra-foveal retina might affect one more than the other enough to cause a noticeable change in the difference between them, but this can scarcely be assumed to be the case when one is only just noticeably different from the other.

[18] The movement was equal in amount to the movement of the head and in the opposite direction.

[19] This frequent shifting of the image from the position previously occupied by it on the retina would give abundant chance for the adapting retina to recover, and thus in terms of the adaptation theory to explain the absence of fluctuation.

less regained through a series of small oscillatory movements as commonly happens before the eye comes to rest in taking a new position. And (2) even were the assumptions true, the argument is not at all differential for Münsterberg's theory. The same effect on fluctuation would be expected in terms of the adaptation theory. An abundant reason was given for the stimulus never disappearing in the effect of the eye-movement on restoring the adapting retina. Eye-movement, it will be remembered, exerts its effect on adaptation in two ways. There is (a) an indirect effect. As the result of the movement the image falls on a fresh area of the retina and the area previously stimulated is given a chance to recover. (b) There is a direct effect which is much greater than the indirect effect, namely, the influence of eye-movement upon the amount and direction of the lymph streams that are continually moving hither and thither in the retina. A detailed discussion of this effect was given in the writer's earlier work.[20] Eye-movement is thus an essential factor in both theories. The relation to fluctuation ascribed to it in the two theories, however, is very different. In Münsterberg's theory, eye-movement helps to cause the disappearance of the stimulus, while in the adaptation theory it is the most important cause of the reappearance of the stimulus. With regard to the relative merits of these two views, the writer will say that a few minutes' observation of a liminal stimulus should be enough to convince anyone that a voluntary eye-movement, for example, instead of causing the stimulus to disappear, will on the contrary serve to keep it distinct; and, if it has disappeared, will cause it to reappear. For a detailed demonstration that involuntary eye-movement acts in the same way and that it is the chief factor in rendering adaptation intermittent, see the writer's earlier articles "An Experimental Examination of the Phenomena Usually Attributed to Fluctuation of Attention," and "The Intermittence of Minimal Visual Sensations."

Münsterberg also conducted a series of experiments in which a comparison was made of the rate of respiration and fluctuation. The results showed that when the respiration was in short quick gasps, the rate of fluctuation was increased; and when it was slow, the rate of fluctuation was decreased. In explaining this result he attributes to breathing an influence on the muscular control of the eye. With the inspiration there is an increase of the muscular control; and with the expiration, a decrease.

The accommodation factor was next taken up by Pace.[21] Pace compared the fluctuations obtained by his subjects before and after the paralysis of their ciliary muscles by a solution

[20] See The Intermittence of Minimal Visual Sensations, *Amer. Jour. Psychol.*, XIX., 1908, 112-129; and The Streaming Phenomenon, *Amer. Jour. Psychol.*, XIX., 1908, 484-503.

In the blinking experiment ,in addition to the effect of the accompanying eye-movement, the blinking would have itself produced an effect on fluctuation. That is, the closing of the lid shut off the light coming from the stimulus and gave the adapting retina a chance to recover.

[21] Edward Pace: Zur Frage der Schwankungen der Aufmerksamkeit nach Versuchen mit der Masson's Scheibe, *Philosophische Studien*, VIII., 1893, 388-403.

of sulphate of atropine, and found no significant difference in his results. He concluded, therefore, that changes in accommodation could not be considered as essential to the phenomenon.

The theory, however, would not down. It was revived by Heinrich, and Heinrich and Chwistek in a series of articles extending from 1896-1907.[22] In the article entitled: "Die Aufmerksamkeit und die Funktion der Sinnesorgane," Heinrich establishes the following principles which he considers of importance in explaining fluctuation. (1) When the attention is directed away from optical impressions (a) the lens takes the curvature characteristic of far seeing, and (b) the lines of sight tend towards the parallel position. The demonstration of these principles, however, cannot be considered as having any very direct bearing on the explanation of the phenomenon of fluctuation, for it may very well be conceived that the voluntary direction of attention away from visual impressions would cause changes in the accommodation and fixation of the eye of a magnitude that would be significant, while the involuntary lapses of attention occurring during the prolonged observation of a stimulus would not cause these changes at all. At least for the purpose of explanation of the phenomenon of fluctuation, the demonstration of the former cannot be considered the equivalent of the demonstration of the latter. And (2) when the attention is directed away from all optical impressions, involuntary changes take place in the curvature of the lens. This conclusion is based upon the recurrent changes that take place in the breadth of the pupil and upon the behaviour of images reflected from the anterior surface of the lens. In drawing this conclusion from the first point of evidence, Heinrich obviously assumes a closer connection between the changes in the breadth of the pupil and changes in accommodation than can safely be done. Any one who has studied the reactions of the pupil under a very wide range of conditions can not help but know that this 1:1 correlation does not exist. Moreover, the connection has not been found in a large enough percentage of cases to make it safe, even plausible, to assume that it exists in any situation in which it has not yet been demonstrated. In his second point of evidence, Heinrich does not describe the behaviour

[22] W. Heinrich: Die Aufmerksamkeit und die Funktion der Sinnesorgane, *Zeitschr. f. Psychol.*, XI., 1896, 410-431; Ueber das periodische Verschwinden kleiner Punkte, *ibid*, XLI., 1907, 59-74, und Zur Erklärung der Intensitätsschwankungen eben merklicher optischer und akustischer Eindrücke, *Bulletin International de l'Academie des Sciences de Cracovie*, Nov., 1898, 363-382.

of the images observed. Apparently, however, the description is supplied in a later paper published in coöperation with Chwistek entitled "Ueber das periodische Verschwinden kleiner Punkte." At least a method of demonstrating changes in the curvature of the lens based on the behavior of the image reflected from its anterior surface is described here. But the validity of this demonstration is strongly open to question. In the experimental section of the present paper it will be shown that it is much more plausible to ascribe this behaviour to involuntary eye-movement than to involuntary changes in accommodation,—that in fact the same kind of behaviour has been described by de Schweinitz[23] and others, in case of the images reflected from the cornea, as one of the common phenomena of ophthalmometry due to eye-movement.

In the article entitled "Zur Erklärung der Intensitätsschwankungen eben merklicher optischer und akustischer Eindrücke,"[24] Heinrich discusses the effect of variation of intensity, or differences in intensity between the stimulus and its background on the fluctuation of visual stimuli. Marbe[25] had found that an increase of intensity increases the phase of visibility, and conversely a decrease of intensity decreases the phase of visibility.[26]

This, Heinrich thinks, is just what should be expected were the disappearances caused by recurring lapses in the adjustment of the lens. As will be shown in the next section of the present paper, however, these results offer no differential evidence in favor of the accommodation theory. They are just what would be expected in terms of any theory that has yet been advanced to explain the fluctuation of minimal visual stimuli. Heinrich also notes that for one of Marbe's observers the

[23] G. E. de Schweinitz: *Diseases of the Eye,* Philadelphia and London, 1902, p. 739.

[24] *Op. cit.,* 366-369.

[25] Karl Marbe: Die Schwankungen der Gesichtsempfindungen, *Philosophische Studien,* VIII., 1893, 615-637.

[26] Marbe apparently was the first to make any separation of the phase of visibility from the phase of invisibility in drawing his conclusions, and even he did not take any account of the phase of invisibility in making his comparisons. The total times of visibility of his stimuli under the different conditions alone were compared. This tendency to break up the total period of fluctuation into its phases for purposes of comparison was a step in the right direction, but it was little heeded by his successors.

Marbe concludes that neither the fluctuation of the "Schrödersche Treppenfigur" nor the visual sensation is periodic. The phase of visibility of the visual stimulus increases with the increase in the difference in intensity between the stimulus and its background. The length of the period of fluctuation is a function of this increase.

phase of visibility was decreased when the image of the stimulus fell on the paraxial portions of the retina. This also, he says, is just what should be expected were the disappearance caused by changes in the curvature of the lens. So is it also what should be expected were adaptation the cause of the fluctuation, for one of the most conspicuous differences between the phenomena in the central and peripheral retina is the greater rapidity of adaptation in the peripheral retina.[27] Again, then, the evidence cannot be considered as differential. Heinrich also takes into consideration in this paper the results of Pace with the atropinized eye. He claims that changes in the curvature of the lens may still be observed when atropine has been used to paralyze the muscles of accommodation. While the present writer by no means contends that the muscles of accommodation are completely paralyzed by the use of atropine, still he would maintain that Heinrich's claim is strongly open to question if it is based on the kind of observation described by him and Chwistek in the article "Ueber das periodische Verschwinden kleiner Punkte." In any event the point is no longer of importance to the explanation of fluctuation, for it has been shown since that time by the present writer[28] that eyes from which the lenses have been removed and which under careful test shown no residual accommodation, get the fluctuation apparently just as readily as the normal eye.

In the article "Ueber das periodische Verschwinden kleiner Punkte," Heinrich and Chwistek, using stimuli of point area, attempt as their *experimentum crucis* to demonstrate the

[27] In fact in the writer's own experiments, designed to show the correspondence between adaptation and fluctuation in the peripheral retina, the farther the stimulus was moved towards the periphery of the retina the shorter became the phases of visibility and the longer the phases of invisibility. These experiments were made differential for the adaptation theory (a) by the method of variation of areas, and (b) by showing a rough correspondence between the phase of visibility in the fluctuation experiments with the adaptation time for different visual stimuli from center to periphery of retina. No. 27 gray and the red, green, blue, and yellow of the Hering series of papers were used as stimuli. Only a partial list of the results obtained was published, however, because the writer did not at that time consider the phenomenon in indirect vision worthy of more space. The main arguments were established for direct vision and no more data were included for indirect vision that were needed to show in a general way that the phenomena here present no exception. (See "An Experimental Examination of the Phenomena Usually Attributed to Fluctuation of Attention," 116-119.)

[28] See An Experimental Examination of the Phenomena Usually Attributed to Fluctuation of Attention, 84 and 94-96.

coincidence of fluctuation and changes in accommodation. Heinrich had mentioned the desirability of making this demonstration in the preceding paper, but had discarded the idea as infeasible because of the conditions under which the experiment would have to be conducted. In choosing to work with point stimuli in this study, Heinrich and Chwistek have admittedly selected the conditions most favorable to the accommodation theory, for by Heinrich's own statement in the explanation of his theory in an earlier paper[29] changes in accommodation would be more apt to cause the disappearance of point stimuli than of stimuli of larger area. Notwithstanding this admission, however, the results they get with point stimuli are advanced in the later paper as evidence that the fluctuation of stimuli of all areas is due to involuntary changes in accommodation. Their work with stimuli of point area will be taken up in detail in the next section of this paper.

III. The Fluctuation of Stimuli of Point Area (the Work of Heinrich and Chwistek)[30]

Heinrich and Chwistek maintain that the fluctuation of visual stimuli of point area is caused by periodic changes in the curvature of the crystalline lens. They also offer their results for stimuli of point area as evidence that the fluctuations of stimuli of all areas are caused by changes in accommodation. Four arguments are advanced by them in support of this conclusion. (1) Periodic changes in the curvature of the lens are directly observable. Moreover, these changes are found roughly to coincide with the fluctuations of the point stimulus when both observations are conducted at the same time. They describe two methods of demonstrating this change of curvature. One may be considered popular, the other technical. The popular demonstration may be conducted as follows. Prick two holes in a cardboard nearer together than the breadth of the pupil of the eye. Hold the card close to the eye and look through the holes at a bright light. The holes will be seen as two dispersion circles with a bright overlapping area. When the curvature of the lens changes, the overlapping area alternately contracts and expands. That is, as the lens becomes more convex, the dispersion circles become smaller and the overlapping area becomes narrower; and conversely, as the lens becomes less convex the circles become

[29] See Zur Erklärung der Intensitätsschwankungen eben merklicher optischer und akustischer Eindrücke, 366-67.

[30] W. Heinrich and F. Chwistek: *Zeitschr. f. Psychol.*, XLI., Abt. 2, 1907, 59-73.

larger and the overlapping area becomes broader. This change in the overlapping area, they say, can readily be observed. Their technical demonstration was accomplished by means of an ophthalmometer. Their method was as follows. Two spots of light were thrown on the eye of the observer by means of two mirrors reflecting the light from a lamp properly placed with reference to these mirrors and to the eye of the observer. These images were observed by means of an ophthalmometer. Their description of method is extremely meager. They say: "Lässt man die beobachtete Person den Punkt fixieren, dessen periodisches Verschwinden untersucht wird, und dreht die Glasplatten des Ophthalmometers, bis man in dem Instrument die beiden von der vorderen Linsenfläche reflektierten Bildchen als drei Punkte sieht, so offenbart sich jede Krümmungsänderung der Linse dadurch, dass der mittlere Punkt bei grösseren Änderungen sich spaltet, bei kleiner breiter wird. Man beobachtet dann ohne weiteres, dass die Linseneinstellung nicht stabil ist, sondern dass sie kleinen periodischen Aenderungen unterliegt. Diese Aenderung konnte mit unserem Instrument durch die Drehung der Platten um höchstens 0.5° kompensiert werden. Es war uns unmöglich die Aenderungsrichtung aus den Bewegungen des Punktes zu erkennen."[31] While these changes in the image reflected from the observer's eye were being recorded by a second person, the observer himself recorded the fluctuations of a point stimulus. Simultaneous records were thus obtained which could be compared in order to determine whether the phases of fluctuations coincided with the phases of changes in the image reflected from the eye. The point stimulus consisted of a small black point on a white ground or a small white point on a black ground, 0.1-0.3 mm. in diameter, observed at a distance of 70-150 cm. Two observers, Herr Sk. and Herr Zacz, were used. The eyes of both were normal, or emmetropic. Chwistek recorded the changes in the images reflected from the eye. Their results are stated as follows. For observer Sk., 776 phases were recorded. "Einseitige Notierung vom Herrn Sk., d. h. notiertes Verschwinden des Punktes ohne entsprechend notierte Akkommodationsschwankung ergab sich in 38 Fällen. Einseitige Notierung vom Herrn Chwistek, d. h. notierte Akkommodationsänderung ohne entsprechende Aufzeichnung des Verschwindens des Punktes fand man in 40 Fällen." For observer Zacz, 296 phases were recorded. "Einseitige Notierung vom Herrn Zacz in 31 Fällen. Einseitige Notierung vom Herrn Chwistek in 32 Fällen."

[31] *Op cit.*, 60-61.

(2) Within the range of areas used by them an increase in the area of the stimulus was found to give longer phases of visibility and shorter phases of invisibility. And, conversely, a decrease in the area of the stimulus was found to give shorter phases of visibility and longer phases of invisibility. Points were observed ranging for one observer (emmetropic) from .2 mm.-.5 mm. in diameter, at distances ranging from 100 cm.-126.5 cm.; for another observer (2.5 myopic), .2 mm.-.5 mm. in diameter at distances ranging from 35 cm.-39 cm.; and for a third observer (4 D. myopic), .2-1.5 mm. at distances ranging from 15 cm.-28.5 cm.

(3) The phase of visibility was also found to vary with the intensity of the stimulus or with the brightness difference between the point and its surrounding field. The greater was this brightness difference, the longer the phase of visibility was found to be as compared with the phase of invisibility, and the less was this brightness difference, the shorter was the phase of invisibility.

(4) When the stimulus was placed just beyond the far point for an observer with myopic eye, it was found to become periodically more and less distinct. Also two points placed at this distance were found alternately to blur into one and to separate into two. Two observers were used in these experiments.

Before passing to his own experimental evidence that involuntary changes of accommodation are not an essential factor in the fluctuation of stimuli of point area, the writer has the following comments to make on the work of Heinrich and Chwistek. (1) In this work they have created for themselves a special problem, that is, they employed stimuli of point area and strongly supraliminal intensity. The fluctuation of such stimuli has never been ascribed to the fluctuation of attention. Historically considered, then, they are not working with the phenomenon to which they primarily make their conclusions apply; and, moreover, they have not in any way shown in a satisfactory manner the propriety of applying their conclusions to the phenomenon explained by Lange as due to the instability of attention. (2) Their popular demonstration of involuntary changes in the adjustment of the lens is strongly open to question. Employing 124 subjects, the writer has not been able to make it work in a single case in which care was taken to rule out extraneous factors which would themselves cause the phenomenon. For example, extreme care must be taken to hold the card steady. Any variation in the distance of the holes from the pupil of the eye will cause a

variation in the breadth of the overlapping area. Especially must care be taken that the card does not touch the lid of the eye, for movements of the ball of the eye and more particularly of the lid change the distance of the card from the eye. These movements are often unnoticed unless the observer is especially looking for them, and are frequently of sufficient range to cause a change in the size of the dispersion circles. Without a doubt the phenomenon, when it has occurred, has been, so far as the writer's experience is concerned, an artifact due to the conditions under which the observations were made. (3) Their technical demonstration by means of the ophthalmometer is, in the writer's opinion, just as strongly open to question. The writer criticizes this demonstration, however, with reluctance because of the meagerness with which they have described their method of working and observations. The following points, however, may be noted. (a) Working as they did, two images should have been observed, one reflected from the cornea, the other from the anterior surface of the lens.[32] Both images should have been very much alike, with the exception that the one reflected from the cornea should have been larger and more distinct. Nothing is said in the article, however, that would give evidence to the reader that more than one image was observed, or that the image described was actually reflected from the lens. But even if it were granted that the image observed was reflected from the lens, it would signify little, for the phenomenon described by them could have been caused just as well by involuntary eye-movements as by changes in the curvature of the lens. That is when the eye is accommodated, the anterior surface of the lens is hyperbolic in shape and varies in curvature considerably from point to point. A movement of the eye would, therefore, cause the rays of light forming the image to be reflected successively from points at which the surface had a different curvature. Each difference in curvature would give a difference in the size of the image reflected. Eye-movement would, therefore, produce the same effect in the size of the image as changes in the convexity of the lens. That is, movements of greater range would correspond in effect to the changes in convexity of greater magnitude, and, conversely, movements of lesser range to the changes in convexity of lesser magnitude. In fact, the phenomenon they describe is one of common

[32] An image reflected from the posterior surface of the lens might also have been observed. But since this image is inverted and is besides very indistinct, it may be considered as having no bearing on the discussion.

observation in case of the corneal image, and in this case no attempt has been made to ascribe it to recurrent changes in the curvature. For example, de Schweinitz, in his treatise on the diseases of the eye, says:[33] "Nothing is more common than to see the images of the mires [the mires correspond to the lights used by Heinrich and Chwistek] separate and overlap so that the apparent curvature of the cornea seems to change while under observation. The changes are due to slight movements of the eye which bring different portions of the cornea into view." We know that there are many involuntary eye-movements per minute even with the best control of fixation that can be obtained.[34] It seems more plausible, therefore, to attribute the phenomenon observed by Heinrich and Chwistek to the involuntary eye-movements which we know occur in abundance, than to use it as a proof of a new phenomenon, namely, the involuntary changes in the curvature of the lens, even if it be granted that the image from the lens was observed. At least, it may be said that Heinrich and Chwistek were not warranted in concluding as they did, without having secured any differential evidence to bear out their conclusion or without even having considered eye-movement as a causal factor. (d) Since the corneal image is known also to double and overlap, a rare opportunity was given to Heinrich and Chwistek, in making these observations, to compare the behaviour of the corneal image with that of the image reflected from the lens, if that really were the image they observed, and to determine by the presence or absence of coincidence in the two sets of changes, whether the doubling and overlapping of the images reflected from the lens has the same or a different cause from the doubling and overlapping of the images reflected from the cornea. Had both images really been observed or had the characteristic doubling and overlapping of the corneal image even been known to Heinrich and Chwistek, one can hardly conceive that their conclusions would have been drawn without recourse to this means of determining whether or not both sets of changes should be ascribed to a common cause. In short, judging from their report as it stands; from the fact that the ophthalmometer as it is ordinarily constructed and used is intended only for the observation of the corneal images, and that such a phenomenon as they describe would

[33] G. E. de Schweinitz: *Diseases of the Eye,* Philadelphia and London, 1902, 739.

[34] See C. E. Ferree: An Experimental Examination of the Phenomena Usually Attributed to Fluctuation of Attention, *Amer. Jour. Psychol.,* XVII., 1906, 113–115; also The Intermittence of Minimal Visual Sensations, *ibid.,* XIX., 1908, 83–112.

have been extremely difficult to observe in case of an image reflected from the lens; and from the fact that descriptions of similar behaviour on the part of the corneal image are given by other observers, the writer cannot help but think, without any wish to be hypercritical, that considerable grounds are given for suspecting that Heinrich and Chwistek have observed the doubling and overlapping of the corneal image which is commonly attributed by de Schweinitz and others to involuntary eye-movement.[35] Moreover, the crux of their argument is that they have actually observed a coincidence between the fluctuation of the visual stimulus and the changes in the adjustment of the lens. This, they contend, gives a certainty to their argument not yet attained in previous work on the problem. But even if the question whether or not it was a lens image that was observed be disregarded, it will be seen from the above discussion that is strongly probable that the coincidence they actually observed was between eye-movement and the fluctuation of the visual stimulus and not between changes in the curvature of the lens and the fluctuation of the visual stimulus.

(4) Their explanation of the effect of variation of area on the fluctuation of a visual stimulus could apply only to stimuli of very small area. Moreover, even in the case of very small areas the effect they got is just what might be expected as the result of increase of area either in terms of Loria's explanation of the fluctuation of stimuli of point area[36] or in terms of the writer's explanation: adaptation interfered with by eye-movement. They make two cases of their explanation of how changes of accommodation cause the fluctuation of stimuli of point area: (a) when the stimulus is a black point in a white ground and (b) when it is a white point in a black ground. In the former case the rays of light coming from the margin of the black point are not sharply imaged on the retina when the lens changes focus, hence they spread over the dark space on the retina corresponding to the black point. It is obvious that this spreading of the marginal light could blot out the dark space only in case the black stimulus were of very small area. Hence the explanation could not apply at all to stimuli of the size ordinarily used in the work on fluctuation. In the latter case the rays of light coming from the white point are not sharply imaged when the accommodation

[35] The writer leaves himself willingly open to correction on this point, however.

[36] See Heinrich and Chwistek: *op. cit.*, p. 60; also Stanislaw Loria: *Untersuchung über das periphere Sehen, Zeitschr. f. Psychol.*, XL., 1905, 160-186.

changes, and are spread over the surrounding dark space. Since strongly supraliminal stimuli were used, it is extremely doubtful whether even very small stimuli could be carried below the limen of sensation from this cause. Moreover, because strongly supraliminal stimuli were used and no attempt was made to control the intensity of the stimulus, an increase in the area of the stimulus would function for sensation as an increase of intensity.[37] Therefore, from this cause alone, according to the theories advanced either by Loria or by the writer, an increase of area would produce an increase in the phase of visibility. Even in case of stimuli of point area, then, the effect of increase of area described by Heinrich and Chwistek offers no differential argument in favor of the explanation advanced by them. Furthermore, the theory of fluctuation of attention was meant to apply only to stimuli of liminal or approximately liminal intensity. When such stimuli are used, an increase of area produces just the opposite effect. For example, working in 1906 with liminal stimuli ranging in area from .5 x .5 cm. to 15 x 15 cm., the writer found that an increase of area caused a decrease in the phase of visibility and a corresponding increase in the phase in invisibility. And in the experimental section of this paper it will be shown that the same effect is produced in case of liminal stimuli of very small area. In both of these cases care was taken to keep the stimuli liminal in order that an increase in the area of the stimulus would not produce an increase in the intensity of the sensation. (4) The fourth argument advanced by Heinrich and Chwistek has no differential value whatever. It was first used by Heinrich in 1898, as applied to stimuli of larger area.[38] A more intensive stimulus, he thinks, is not so liable to be blotted out by involuntary changes in accommodation. Therefore, he concludes, the more intensive is the stimulus the longer should be the phases of visibility and the shorter the phases of invisibility. It is obvious, however, that this result is just what should be expected from adaptation as a causal factor. It should be expected even were it held that fluctuation is due to instability of attention. In fact an increase in the phase of visibility and a decrease in the phase of invisibility would be the natural consequence of an increase in the

[37] We seem to have here a violation of one of the most fundamental principles in experimental procedure, namely, when it is wanted to determine the effect of a given factor, the effect of all other factors should, if possible, be eliminated from the results of the experiment.

[38] W. Heinrich: Zur Erklärung der Intensitätsschwankungen eben merklicher optischer und akustischer Eindrücke, *Bulletin International de l'Academie des Sciences de Cracovie,* Nov., 1898, 363-382.

intensity of the stimulus in terms of any theory that has yet been advanced to explain fluctuation.

(5) The writer is in some doubt as to what is meant by the fifth argument. "Befindet sich der Punkt, dessen Verschwinden man beobachtet, innerhalb des Akkommodationsbereiches der Linse, so beobachtet man nur das periodische Verschwinden desselben. Die Verhältnisse sind komplizierter, wenn man den Punkt ausserhalb des Fernpunktes aufstellt was beim myopischen Auge leicht ausführbar ist. In diesem Falle zeigt sich, dass der beobachtete Punkt, der jetzt nicht scharf gesehen wird, periodisch verschwindet, aber auch periodisch schärfer gesehen wird."[39] In the first place he cannot understand why the above result should be expected, were changes in accommodation present, for when the far point is actually reached the ciliary system should be completely relaxed. It is difficult then to see how the lens can be allowed to become any flatter, unless indeed it be held that the theory of accommodation commonly accepted for the human eye is incorrect. And in the second place, working under the conditions described by Heinrich and Chwistek, the writer has been unable to get anything that might be called three distinct and separate stages of clearness of his stimulus. Moreover, any stimulus of supraliminal intensity, fluctuating from any cause whatsoever and especially from causes purely retinal, would be apt to have, although not sharply defined, maximum, minimum, and intermediate degrees of distinctness. This the writer's observers were able to get at whatever distance the stimulus was put from the eye, but they were utterly unable to detect the three distinct and separate stages that are reported by Heinrich and Chwistek. Nor were they ever able to see the stimulus as clearly beyond the far point as they were at the far point or nearer than the far point. In short, there was never at this point what could be considered a norm of clearness which was succeeded either periodically or even at irregular intervals by a degree of clearness in excess of this norm. Continuing, Heinrich and Chwistek say: "Das lässt sich am besten durch folgendes Experiment illustrieren: Stellt man nicht weit ausserhalb des Fernpunktes des myopischen Auges als Objekt zwei Punkte, die so nahe liegen dass sie als ein Fleck gesehen werden, so beobachtet man, dass die Punkte periodisch auf kurze Zeiten getrennt erscheinen." The writer has not succeeded in getting this phenomenon when working beyond the far point with the myopic eye. It is, however, of common occurrence for any eye when the points are placed

[39] *Op. cit.*, 66.

at or slightly nearer than the limit of clear vision for these points and are regarded for any length of time. The points alternately blur into one and separate into two. In all probability both retinal and accommodation factors are involved in this result, but no definite estimate can be made of how much importance should be assigned to either until comparative records be made for subjects without lenses and for normal subjects. In the writer's opinion, however, the above experiment comes the nearest of any yet described by Heinrich and Chwistek to giving tangible evidence that involuntary changes in accommodation occur. But even to demonstrate clearly that these changes occur, would not prove that they are essential or even important factors in the fluctuation of minimal visual stimuli even of point area.[40] That they are not essential factors will be shown by the writer in the next section of this paper.

IV. Experimental

In this section of our paper we propose to show (1) that involuntary changes in accommodation are not essential or even important factors in the fluctuation of minimal visual stimuli of point area, and (2) that, identified by tests used by the writer in his earlier experiments, these fluctuations correspond just as closely to adaptation phenomena as they do for stimuli of larger area.

Probably the most convincing proof that one can offer that involuntary changes of accommodation are not essential to the fluctuation of stimuli of point area is the results obtained from aphakial subjects. Observations were made by the writer upon four aphakial subjects. They were all above sixty years of age, and three were above seventy. All of them had had the lenses removed from their eyes from 15-20 years before. Both the advanced age of the subjects and the long period that had elapsed since their lenses were removed favored the absence of any residual accommodation. To make sure of this point, however, they were each tested as follows. The subject's head was clamped in a head-rest and a card bearing letters of very fine print (3½ point type) was slid along a meter rod supported at the level of his eyes in the

[40] Lest it be thought that this experiment shows some coincidence between changes in accommodation and fluctuation, it may be pointed out that the cycle of changes experienced by the two points does not even include disappearance. The points merely blur into one and separate into two. That is, the only phenomenon cited by Heinrich and Chwistek that really gives any tangible evidence of involuntary changes in accommodation does not even occur in a series in which fluctuations are found.

median plane. The card was placed at his point of clearest vision as determined by the focus of his glasses and was moved both nearer and farther until just noticeable dimming took place. Every precaution was taken to secure accuracy. For one of the subjects the card could not be moved more than 2 mm. from the point of clearest vision without becoming less distinct. Very little more movement was required for any of the subjects. It may be safely said that all were practically without accommodation. Two of these observers were the same as were used by the writer in the earlier investigations made with stimuli of larger area. Opportunity was thus had to determine whether or not changes in accommodation play a more important rôle in the fluctuation of stimuli of point area than of stimuli of large area. So far as could be told from the records in both cases, they do not play a more important rôle. In cases of stimuli both of large and of very small area, the fluctuations occur for the aphakial subject with apparently no greater variation from the normal subject than is found from individual to individual with normal eyes.

Of the methods used in the former work to demonstrate that fluctuation is a phenomenon of the adaptation of the sense organ, only three were available for stimuli of point area. In the first of these the stimuli were made of different colors. Speaking of this method in the first paper[41] of the former series, the writer says, " Colors and grays were found to have an order of fluctuation times corresponding to their adaptation times. Four colors, red, green, blue, and yellow, gave very different fluctuation periods as compared with each other and with No. 27 Hering gray. The visibility times obtained were in the following order: red, green, blue, and yellow, the yellow being nearly four times as long as the red.

" The complete adaptation times for sheets of the same colors were found to have the same order of length and a rough correspondence as to ratio of length. Further, a striking fact came out with regard to the phases of invisibility. Since red, for example, has a shorter phase of visibility than green, one might naturally expect that its phase of invisibility would also be shorter than the phase of invisibility of green. The reverse, however, is true. Red has a longer invisibility than green, and this peculiarity is especially marked if one considers the proportionality between the phases, *i. e.*, the ratio invisibility: visibility. The same thing is true of the complementaries blue

[41] An Experimental Examination of the Phenomena Usually Attributed to Fluctuation of Attention, p. 86.

and yellow. Clearly, we cannot look for a central explanation of this peculiarity; but it seems just what we might expect of adaptation from the standpoint of the compensation theory. The recovery process for the red is the green process. The green process is longer and seemingly more tenacious than the red, as is shown by the adaptation experiments proper, and is further borne out by the longer duration of the green after-image. A similar relation obtains in the blue-yellow process." In the earlier work, the stimuli were gotten as follows. Squares of the color of the size that was wanted were pasted on a gray of the brightness of the color. The stimulus was rendered liminal by letting the light pass from the colored paper through a sheet of milk glass, matt on one side, placed at such a distance from the color as to render its intensity liminal. The intensity was easily regulated by slight changes in the distance of this glass from the colored paper. The light reflected from the colored papers could not be used, however, for stimuli of point area, because the milk glass mentioned above had to be used to reduce the intensity of the stimulus and it was impossible to get this glass thin enough to give noticeable color with stimuli of point area. Light was transmitted through color-filters instead. The stimulus was gotten as follows. A hole was pricked through a gray cardboard with a fine needle and covered with one or more layers of colored gelatin. In front of the card, in contact with it, was placed the sheet of milk glass, matt on one side. The hole was illuminated by a row of lights placed behind the cardboard, normal to its surface, at a distance sufficient to render the stimulus liminal. By this arrangement a just noticeable point of color was presented to the observer seated in front.

A stimulus given by reflected light has always yielded more differential results in former experiments with the method of colors than a stimulus by transmitted light. This is probably due to the fact that we were able to get from the former type of stimulus more color in proportion to the white light present, thus better bringing out the color differences in the liminal stimuli. The poorer method had to be used, however, because as stated above milk glass with one surface matt could not be obtained thin enough so that a point of colored paper pasted upon a background of equal brightness could be seen through it.[42]

[42] In case of the colored papers the liminal stimulus and surrounding field were of the same brightness, because the paper giving the stimulus was pasted on a gray of the brightness of the color. The only effect of the milk glass in front was to change the general scale of brightness of color and surrounding field. No brightness inequality was produced.

The registration of results was secured by means of a Ludwig-Baltzar kymograph, a telegraph key and an electro-magnetic recorder, a Jaquet chronograph (set to seconds), and a lamp rheostat to cut down the current from the lighting circuit. All of this apparatus was screened from the observer by means of a sliding curtain. The work was done in a long room with the windows all at one end. Thus cross lights, unequal illumination of the background, etc., could be avoided. The illumination of the room was kept fairly constant by means of thin curtains covering the windows.[43] The observer sat with his back to a high window and his head in a head-rest fastened to the edge of a long table, along which the frame bearing the stimulation apparatus was moved as required. The time used throughout was 1 sec. The following results were obtained. As in the earlier work with stimuli of a larger area, red showed a shorter phase of visibility and a longer phase of invisibility than green; and blue, a shorter phase of visibility and a longer phase of invisibility than yellow. In spite of the poorer method we were required to use, the results obtained were almost as strongly marked as they were when the same method was used with stimuli of a larger area. These results have been verified at the time this work was done and since by a large number of observers practiced and unpracticed. The results of three observers chosen as typical will be reported here. Tables I-III have been compiled from these results.

TABLE I

OBS. C.—Fluctuation with stimuli of the four principal colors of point area showing that the phases of visibility and invisibility have the characteristic adaptation and recovery peculiarities of these colors just as they have with stimuli of larger area.

Stimulus	Vis.	M.V.	Invis.	M.V.	Vis. ÷ Invis.	Invis. ÷ Vis.	Period
Red	4.36	.79	1.68	.65	2.585	.385	6.04
Green	5.30	.93	1.13	.42	4.690	.213	6.43
Blue	7.75	1.12	1.41	.71	5.496	.181	9.16
Yellow	13.10	1.76	1.32	.59	9.925	.100	14.42

In the case of the stimulus by transmitted light, this result was not so effectively secured because of the greater difficulty of equating the point of light and the surrounding field.

[43] To keep the illumination constant presupposes a means of measurement. At the time the writer had at his command no means of measuring the illumination of a room by daylight. For a method of

TABLE II

Obs. G.

Stimulus	Vis.	M.V.	Invis.	M.V.	Vis. ÷ Invis.	Invis. ÷ Vis.	Period
Red	5.1	1.12	1.26	.54	4.047	.247	6.36
Green	7.43	1.54	1.14	.37	6.517	.153	8.57
Blue	10.9	1.59	1.46	.52	7.466	.133	12.36
Yellow	Did n ser	ot fluc vation.	tuate	at all	during	period	of ob-

TABLE III

Obs. Ca.

Stimulus	Vis.	M.V.	Invis.	M.V.	Vis. ÷ Invis.	Invis. ÷ Vis.	Period
Red	1.82	.59	1.62	.32	1.123	.890	3.44
Green	2.82	.53	1.27	.36	2.243	.450	4.09
Blue	4.15	.55	1.70	.35	2.441	.409	5.85
Yellow	5.22	.86	1.52	.51	3.434	.291	6.74

In the second test strips of colored paper of the breadth of a point and 5 cm. in length were used.[44] They were pasted on a gray background of the brightness of the color in each case and were observed as liminal color on the matt surface of the milk glass placed in front. They were arranged first with their longer dimension in the vertical plane, then in the horizontal plane. The former arrangement favored a maximal disturbance of adaptation for observers having the greater range and frequency of eye-movement in the horizontal plane, and gave with these observers in the fluctuation experiments a corresponding increase in the phase of visibility and decrease in the phase of invisibility. Conversely, the latter arrangement favored a minimal disturbance of adaptation for these observers and gave a corresponding decrease in the phase of visibility and increase in the phase of invisibility.

doing this, see C. E. Ferree and Gertrude Rand: An Optics-Room and a Method of Standardizing Its Illumination, *Psychol., Rev.*, XIX., 1912, 364-373.

[44] In this test we were able to use colored paper because strips, although only of the breadth of a point, could be seen when 5 cm. long through the sheet of milk glass we used.

For each observer careful records were made of the frequency and range of movement and the total time the eyes were moving according to the methods described in the former papers.[45]

Speaking of this test in the first paper of the former series, the writer says, pp. 84-90, " A more direct experimental confirmation than was afforded by the method of variation of areas of this view that eye-movement interferes with the course of adaptation and is also the conditioning factor for the wide range of variability found in the phases of visibility and invisibility in the fluctuation experiments, is given by the following results. An examination of average frequency of eye-movement in the horizontal and vertical planes during fixation showed that three of our observers had a marked excess in both frequency and range in the horizontal, while the fourth had an excess of frequency in the vertical, but of range in the horizontal plane. This appeared to mean that for three observers, there was greater change of stimulation, and consequently greater relief for the adapted elements, in the horizontal than in the vertical direction; while the reverse was true, though probably to a lesser degree, for the fourth. To test this interpretation, stimuli longer than broad were used, *e. g.*, slips of paper 5 mm. x 40 mm. When these were placed with the longer dimension vertical, the shorter dimension would fall in the direction of greater unsteadiness of fixation for the three observers who had the excess of eye-movement in the horizontal plane. Consequently, a maximal interference with adaptation for these stimuli would be obtained, and one might expect an increase in the phase of visibility and a decrease in the phase of invisibility. On the other hand, if the longer dimension were placed in the horizontal and the shorter in the vertical plane, the minimal interference possible for these stimuli would be secured, and a decrease in the phase of visibility and an increase in the phase of invisibility should ensue. For the fourth observer with the stimulus arranged as described above, the reverse should be true, but probably not in so marked a degree, since his range was greater in the horizontal, which fact to a certain extent would counteract the effect of frequency. . . . . That these methods of arrangements of stimulus caused a marked change in the phases of visibility and invisibility for each

[45] See An Experimental Examination of the Phenomena Usually Attributed to Fluctuation of Attention, 113-115; and The Intermittence of Minimal Visual Sensation, 84-87.

observer will be seen by inspecting the Tables. Indeed the correspondence between the quantities: $\frac{\textit{Visibility} \div \textit{invisibility}}{\textit{visibility}^1 \div \textit{invisibility}^1}$, and $\frac{\textit{frequency}}{\textit{frequency}^1}$, is much closer than was anticipated."[46]

The results for the strips of point breadth are given in Tables IV-VI. For all the observers whose results are given in these tables, both the range and frequency of eye-movement were greater in the horizontal than in the vertical plane.

The third test was based upon the fact that the time required for a colored stimulus to adapt depends to some extent upon the surrounding field.

The question of what is meant by adaptation is logically raised here; among the followers of the Hering theory, it has come to mean, apparently, simultaneous induction, and Aall, reviewing the writer's first article,[47] assumes that that is what is meant by adaptation in that

TABLE IV

Obs. H.—Fluctuation with horizontal and vertical arrangement of the stimulus. Showing how arrangements that favor maximal and minimal interference with adaptation affect the phases of visibility and invisibility. Stimulus 3 mm. x 50 mm.

Stimulus	Arrangement	Vis.	M.V.	Invis.	M.V.	Vis. ÷ Invis.	Invis. ÷ Vis.	Period
Red....	Vertical....	2.95	.64	1.68	.31	1.756	.569	4.63
"	Horizontal..	1.08	.23	2.29	.40	.471	2.120	3.37
Green...	Vertical....	4.04	.72	1.45	.26	2.786	.358	5.49
"	Horizontal..	1.69	.38	1.76	.37	.960	1.041	3.45
Blue....	Vertical....	5.40	.86	2.03	.51	2.660	.376	7.43
"	Horizontal..	2.51	.49	3.10	.46	.806	1.235	5.61
Yellow..	Vertical....	6.99	.97	1.45	.29	4.82	.207	8.44
"	Horizontal..	3.55	.72	2.10	.56	1.928	1.690	5.65

[46] For a more complete understanding why arranging the shorter dimension of the stimulus in the direction of the greatest eye-movement causes relatively long phases of visibility and short phases of invisibility; and conversely arranging the longer dimension of the stimulus in the direction of greatest eye-movement causes relatively short phases of visibility and relatively long phases of invisibility, see The Intermittence of Minimal Visual Sensations, 112-129; and The Streaming Phenomenon, 484-494.

[47] *Zeitschr. f. Psychol.*, XLIII., *Abt.* 2, 1906, 456-457.

TABLE V

Obs. R.

Stimulus	Arrangement	Vis.	M.V.	Invis.	M.V.	Vis. ÷ Invis.	Invis. ÷ Vis.	Period
Red....	Vertical....	3.60	.75	1.46	.24	2.548	.405	5.06
"	Horizontal..	1.14	.28	3.40	.75	.335	2.982	4.54
Green...	Vertical....	4.30	.62	1.39	.19	3.093	.323	5.69
"	Horizontal..	2.42	.47	2.36	.37	1.025	.975	4.78
Blue....	Vertical....	4.93	1.08	1.68	.34	2.933	.340	6.61
"	Horizontal..	2.95	.54	4.53	.89	.651	1.535	7.48
Yellow..	Vertical....	6.61	1.23	1.46	.31	4.527	.220	8.07
"	Horizontal..	3.26	.79	2.75	.49	1.189	.843	6.01

TABLE VI

Obs. G.

Stimulus	Arrangement	Vis.	M.V.	Invis.	M.V.	Vis. ÷ Invis.	Invis. ÷ Vis.	Period
Hering gray No. 27	Vertical....	8.48	1.32	2.03	.39	4.177	.239	10.51
"	Horizontal..	3.14	.71	3.21	.56	.978	1.022	6.35
Red....	Vertical....	5.09	1.12	1.84	.29	2.766	.361	6.93
"	Horizontal..	1.65	.38	3.61	.78	.457	2.187	5.26
Green...	Vertical....	7.42	1.29	1.94	.41	3.824	.261	9.36
"	Horizontal..	2.52	.48	2.98	.48	.845	1.182	5.50
Blue....	Vertical....	8.99	1.47	2.84	.39	3.165	.315	11.83
"	Horizontal..	3.88	.84	5.99	.97	.647	1.542	9.87
Yellow..	Vertical....	11.49	1.97	1.90	.32	6.047	.165	13.39
"	Horizontal..	4.84	.97	3.86	.89	1.254	.797	8.70

article. The writer, however, by no means believes that the tendency of a color to lose its saturation on prolonged exposure to the eye or of all grays to become mid-gray is due entirely or even to any considerable extent to simultaneous induction. He grants an influence to the surrounding field when there is a surrounding field, and is at present making a quantitative study of that influence, but it is obvious that the influence of the surrounding field can have no part in the phenomenon called general adaptation, for in that case the whole retina is stimulated by the same kind of light. It can apply to local adapta-

tion alone and even in local adaptation it cannot be considered a factor of primary importance. In 1838–1840 the loss of saturation experienced by a color on prolonged exposure to the eye was explained by Fechner[48] as due to the exhaustion or fatigue of the retinal elements. This explanation was adopted by Helmholtz, and became a feature of the Young-Helmholtz theory. Hering,[49] however, following a suggestion made by Godart, 1776,[50] and elaborated by Plateau, 1833-1835,[51] chose rather to consider the retina compensating in function. A compensating retina, it is obvious, should not exhaust. Hering bore himself out in this general position by claiming that the eye is ordinarily exposed to stimulation by white light from 15-18 hours during the course of a day, and yet at the end of that time it has not noticeably lost in its sensitivity to white light.

Hering himself apparently has not based his claim on experimental evidence. At least he neither offers results of his own nor quotes from the work of others. His conclusion seems to be drawn wholly from general observation. He says (Ueber Ermüdung und Erholung des Sehorgans, *Arch. f. Ophthal.*, XXXVII., 1891, (3), p. 2): "Anderseits ist es eine bekannte Thatsache, dass wir des Abends nicht merklich schlechter sehen als des Morgens und dass dies auch dann noch der Fall ist, wenn dem Tage eine in hellen Raumen durchwachte Nacht und ein neuer schlafloser Morgen folgt. Also einerseits fortwährende Ermüdung und zwar eine so schnell—vor sich gehende, dass schon nach einer wenige Secunde währenden—Fixierung eines weissen Objects auf dunklem Grunde sich die Folgen der "Ermüdung" durch ein deutliches negatives Nachbild verrathen, und anderseits trotz solcher fortwährenden raschen Ermüdung keine merkliche Beeinträchtigung des Lebens selbst bei tagelanger Belichtung der Netzhaut." He contends (p. 1) that according to the theory of fatigue, advocated by Helmholtz and Fick, this should not be. During an exposure of several hours to white light, the eye never has a chance completely to recover, hence should become from beginning to end of the period progressively more fatigued.

This conclusion is not at all in agreement with experimental results obtained by C. F. Müller (Versuche über den Verlauf der Netzhautermüdung. Diss. inaug., Zürich. 1866), for example, who from the results of his tests of the loss of sensitivity of the eye to white light from morning to night, concludes: "Am Abende erscheint der Retina irgend ein Object nur in 0.49 derjenigen Helligkeit, in welcher es ihr am Morgen erschienen wäre." Moreover, he found that the shape of the curve of fatigue undergoes a very decided change during the course of the day. Aubert also disagrees with Hering. He says

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[48] G. T. Fechner: *Pogg, Ann.*, XLIV., 1838, 221, 513; XLV., 1838, 227; L., 1840, 193, 427. The theory was conceived earlier by Scherffer (*Abhandlung von den zufälligen Farben*, Wein, 1765; also *Journal de Physique de Rozier*, XXVI., 175, 273), who explained the negative after-image by the conception that the retina is diminished in sensitivity by fatigue produced by previous stimulation.

[49] Ewald Hering: *Zur Theorie vom Lichtsinne*, 1874; *von Graefe's Archiv*, XXXVII., 1891, (3), 1, and 1892, XXXVIII., (2), 252.

[50] de Godart: *Journal de Physique de Rozier*, VIII., 1776, (1), 269.

[51] Plateau: *Ann. de Chimie et de Physique*, LIII., 1833, 386; LVII., 1835, 337: *Pogg. Ann.*, XXXII., 1834, 543. More fully in *Essai d'une théorie générale, etc. Mem. de l'Acad. de Belgique*, VIII., 1834.

(Moleschott's Untersuchungen, VIII., 1862, 251; see also Beiträge zur Physiologie der Netzhaut. *Abhandlungen der Schlesischen Gesellschaft,* Breslau, 1861, 39): "Es erscheint mir also aus obiger Bemerkung hervorzugehen, dass *im Laufe des Tages durch die Einwirkung des Lichtes die Empfindlichkeit unserer Retina fortwährend abnimmt,* so dass wir am Abende weniger empfindlich gegen Licht sind, als des Morgens." Moreover, without supporting evidence either from general observation or from experiments on color, in fact in complete disregard of this evidence, Hering, as he has done in many other cases in his work on the optics of color, has generalized with regard to the retina's response both to white light and to colored light from the results of observations with white light alone. For example, it is scarcely necessary to point out that the eye cannot be exposed from 15-18 hours to colored light without loss of sensitivity to color. Without dwelling further, however, on the evidence for and against a compensation theory, it will be sufficient for our purpose here to point out that if one were to hold to a compensation theory in the Hering sense, it would be necessary for him to seek some other explanation than exhaustion for the loss of sensitivity of the eye, apparent or real, to color or brightness. Hering apparently conceives that this happens only in case two surfaces of different quality are juxtaposed, and then all that takes place is that each is induced over the other and the qualitative difference between the two tends to disappear. There is, then, no real loss of sensitivity of the eye to either. Both become alike because by induction they are mixed to equality. The following objections may be offered to the explanation. (1) As stated before, it cannot apply to general adaptation. Yet it is well known that the eye loses its sensitivity to color when the whole retina is stimulated by that color, in fact more rapidly than when only a part is stimulated, except perhaps in case of certain combinations of color and surrounding field. (2) It can apply to local adaptation only in case the two fields juxtaposed both belong to the brightness series. For example, when the eye is exposed for some length of time to a white surface contiguous to a black or a light gray to a dark gray, the lighter surface is observed to darken and the darker to lighten. This might be explained by the mixture of the two qualities by induction. The evidence afforded by the observation, however, is not at all differential, for the phenomenon may be explained just as well by exhaustion. A different situation entirely is presented, however, when the two contiguous surfaces are colored. In this case there is very little in the phenomenon that could by the most favourable interpretation be construed as a mixture to an intermediate color quality. For example, when red and blue are stared at in juxtaposition, we should expect, in terms of Hering's explanation, both surfaces to become purple with no more loss of saturation than would be attendant upon distributing each color uniformly upon both surfaces. This, however, is not at all what takes place. The prominent effect is loss of saturation. The two surfaces tend to become alike for the most part only because both tend towards gray. The blue, it is true, does acquire a tinge of violet, but it does this as the result of adaptation even when red is not juxtaposed. It probably does become slightly more reddish by being alongside the red, but the evidence of induction is not great. The red, likewise, may be modified a little by being alongside the blue, but the effect is even less noticeable than it is for the blue. Similar results are gotten with

green and yellow. In case the colors juxtaposed are complementary colors, the results of induction should be towards a cancellation to gray. But again the tendency towards gray which is actually observed affords no differential evidence for this theory of induction, because the shift towards gray can be explained just as easily in terms of the exhaustion theory. And that induction can have little to do with the phenomenon may be shown by the facts (1) that the tendency would have been towards gray had the whole retina been stimulated by one of the colors alone, and (2) that so far as can be told, the process is hastened little, if any, by the juxtaposition of the two colors. In the Lichtsinne, 1878, pp. 36-37 Hering describes the experiment upon which he bases his explanation of adaptation in terms of simultaneous induction. His device for stimulating the eye consists of a white and black surface juxtaposed. No attempt is made to extend the experiment to color. Moreover, in drawing his conclusions, no heed whatever is given to what would happen were the whole retina stimulated by light of one quality. This is a truly remarkable instance of a broad generalization made from a slender basis of fact.

The writer, then, does not wish it to be understood that he explains the fluctuation of minimal visual stimuli in terms of simultaneous induction. He has called this fluctuation a phenomenon of the adaptation and recovery of the sense organ, meaning by adaptation here, as in the original article, the progressive loss of sensitivity of the eye to colored and to colorless light caused by prolonged exposure. Just what the factors are in adaptation, will be made the subject of a further paper. They vary under different circumstances. In case of local adaptation, simultaneous induction is one of the factors, and in certain especial cases it may exert considerable influence, as is recognized in the test described above; but to make it the sole cause of the adaptation of the eye to its stimulus seems to the writer, in the face of the experimental evidence, to be little short of absurd.

In the earlier experiments it was found that by keeping the surrounding field constant and varying the stimulus, or conversely, by keeping the stimulus constant and varying the surrounding field, a difference in the period of fluctuation was obtained, showing itself chiefly in the phase of visibility. The same thing held in the recognized adaptation experiments. The variations in the phases of visibility and invisibility that were produced in the one, were produced in the other; the only departure from precise correspondence being that the differences were more marked in case of the recognized adaptation experiments, as would be expected from the longer duration of the process. The old series of Hering papers was used both in these experiments and in the experiments with stimuli of point area because combinations more favorable to rapid adaptation could be found in this series. Some of the combinations most favorable were the vermilion of the series on the blue-green, and the vermilion upon Hering gray No. 27; and some of the most unfavorable combinations were dark

red on yellow, and dark blue on yellow. The combinations favoring rapid adaptation gave in the fluctuation experiments a short phase of visibility and a long phase of invisibility, and conversely, the combinations unfavorable to rapid adaptation gave long phases of visibility and short phases of invisibility. Although the writer had carefully determined in an earlier experiment with large areas which were the favorable and which the unfavorable combinations, still in order to make the correspondence between fluctuation and adaptation still more complete, in cases of stimuli of very small area both adaptation and fluctuation experiments were conducted in the present study. As was the case in the earlier experiments, the advantages of a stationary stimulus and surrounding field had to be sacrificed in these experiments, because the use of the milk glass to reduce the saturation of the stimulus, as was done when a stationary system was used, would also have reduced the saturation of the color in the surrounding field. This would not have been desirable for the purpose of the experiment. Accordingly, the Masson disc with the broken radius of point breadth was substituted for the stationary system. In case of the adaptation experiments, a point of color of full intensity was pasted upon the various backgrounds and observed at the proper distance. In conducting this adaptation series with stimuli of point area, we were not only getting the results needed for comparison in our fluctuation series, but by using stimuli of full intensity, we were applying our test under precisely the same conditions used by Heinrich in his fluctuation experiments. In both cases the effect of the favorable and unfavorable combinations was plainly marked in the results. For the results of these experiments see Tables VII-X.

TABLE VII

Obs. R.—Showing that combinations that influence adaptation time correspondingly influence fluctuation for stimuli of point area just as they do for stimuli of larger area. Fluctuation series, stimulus-ring 0.3 mm. broad and of liminal intensity.

Stimulus	Background	Vis.	M.V.	Invis.	M.V.	Vis. ÷ Invis.	Invis. ÷ Vis.	Period
Red....	Blue.......	4.258	.81	1.930	.83	2.220	.450	6.215
Red....	Orange.....	6.041	.98	1.327	.59	4.552	.219	7.368
Red....	Yellow-green	6.10	.91	.933	.32	6.538	.152	7.033
Yellow..	Red........	9.166	1.10	1.125	.26	8.147	.122	10.291

TABLE VIII

OBS. B.

Stimulus	Background	Vis.	M.V.	Invis.	M.V.	Vis. ÷ Invis.	Invis. ÷ Vis.	Period
Red....	Blue.......	3.30	.82	2.871	.88	1.149	.870	6.171
Red....	Orange.....	5.083	.94	2.416	.75	2.103	.475	7.499
Red....	Yellow-green	4.125	.59	1.540	.64	32.678	.373	5.665
Yellow..	Red........	6.230	.94	1.050	.32	5.933	.168	7.28

TABLE IX

OBS. R.—Showing that combinations that influence adaptation time correspondingly influence fluctuation for stimuli of point area just as they do for stimuli of larger area. Adaptation series, stimuli of point area and of full intensity.

Stimulus	Background	Vis.	M.V.	Invis.	M.V.	Vis. ÷ Invis.	Invis. ÷ Vis.	Period
Red...	Blue.......	13.0	1.09	2.577	.76	5.044	.198	15.577
Red...	Orange.....	11.323	.90	1.112	.58	10.182	.098	12.435
Red...	Yellow-green	11.032	.87	.781	.32	14.122	.070	11.813
Yellow.	Red........	200.	No	fluctu	ation.			

TABLE X

OBS. B.

Stimulus	Background	Vis.	M.V.	Invis.	M.V.	Vis. ÷ Invis.	Invis. ÷ Vis.	Period
Red...	Blue.......	5.761	.59	5.833	.654	.987	1.012	11.594
Red...	Orange.....	6.636	.98	4.723	.76	1.405	.711	11.359
Red...	Yellow-green	10.751	1.05	4.854	.97	2.215	.451	15.605
Yellow.	Red........	200.	No	fluctu	ation.			

V. Conclusion

In conclusion the following points may be reviewed. (1) The work offered by Heinrich and Chwistek in support of the accommodation theory for the fluctuation of stimuli of point area was done with stimuli of full intensity. In using stimuli of this intensity Heinrich and Chwistek have created for themselves a special problem. The doctrine of fluctuation of attention has never been applied to the fluctuation of stimuli

strongly supraliminal in intensity. (2) Their strongest and most direct argument for the accommodation theory is their claim of having directly demonstrated a coincidence between involuntary changes of accommodation and fluctuation. The validity of this claim, however, rests primarily upon whether or not they have given a valid demonstration of the involuntary changes in accommodation. Their demonstration of involuntary changes in accommodation is strongly open to question. Employing 124 observers, the writer has been unable in a single case to make their popular demonstration work when care was taken to rule out extraneous factors which would themselves cause the phenomenon. And their technical demonstration with the ophthalmometer is in terms of a phenomenon which is described by de Schweinitz and others as one of the common phenomena of ophthalmometry due to eye-movement. The coincidence, then, which they claim to have observed between the fluctuation of stimuli of point area and changes in the curvature of the lens, is in all probability a coincidence between eye-movement and fluctuation. (3) Moreover, none of the evidence they have offered as indirectly proving the accommodation theory can be considered in any sense differential. All of it can be explained just as easily either in terms of the writer's adaptation theory or in terms of Loria's theory for the fluctuation of stimuli of point area. Some of it can even be explained in terms of any theory that has yet been advanced to account for the fluctuation of minimal visual stimuli. (4) The fluctuation of stimuli of point area presents no especial case. For (a) involuntary changes in accommodation are not an essential factor in these fluctuations. They take place for aphakial subjects apparently just as readily as for subjects with normal eyes. And (b) identified by the tests used by the writer in his earlier work these fluctuations correspond just as closely to adaptation phenomena as do the fluctuations of stimuli of larger area. (5) The fluctuation of minimal visual stimuli whether of large or small area is a phenomenon of the adaptation and recovery of the sense organ. And by adaptation is meant the progressive loss of sensitivity to colored and colorless light caused by prolonged exposure of the eye to these lights. It is not simultaneous induction. Simultaneous induction can be considered only as a minor factor in the adaptation of the eye to its stimulus.